CO_2 mitigation and the Indian transport sector



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Tata Energy Research Institute

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Preface

The earth's capacity for absorbing and assimilating most human generated pollutants is large, but limited. As pollution rates rise due to increased human activity, the natural processes that absorb and assimilate pollutants are eventually overwhelmed, leading to rising concentrations. In some cases, this can lead to imbalances in the global environment. In November 1995, the IPCC (Intergovernmental Panel on Climate Change), an official scientific group set up by WMO (World Meteorological Organisation) and UNEP (United Nations Environment Programme), concluded that *the balance of evidence suggests a discernible human influence on global climate*. Average global surface temperature has increased by about 0.3 °C to 0.6 °C over the last century and the recent years have been the warmest since 1860. Global sea level has risen by 100–125 mm over the past 100 years and much of this could be attributed to temperature increases. Temperatures will rise substantially in the future. If policies to reduce CO_2 emissions from current levels are not implemented, the IPCC estimates that the average global surface temperature would rise by 2 °C between 1990 and 2100—an average rate of warming greater than any seen in the last 10 000 years.

Such changes in the earth's climate would have far reaching impacts. A warmer future would lead to very high sea level rise (estimated at an average of 500 mm by 2100). Warmer temperatures will also result in a more vigorous hydrological cycle implying more evaporation and more precipitation resulting in more severe floods and droughts in places. There would be an increase in rainstorms, tropical cyclones, and other catastrophic events.

To understand the nature and the extent of economic impacts of climate change better, TERI (Tata Energy Research Institute) undertook a project titled *India country study on global warming impacts*, sponsored by the Ford Foundation. In addition to studying the impact of climate change, the study was expected to collect, compile, and disseminate data and information related to global warming in order to create an understanding, spread awareness, and sensitize people to the risks of climate change.

The publications in the series are:

- *How global is global and how warm is warming?* Introduces the problem of global warming and climate change, underlines the issues and challenges involved, highlights the projections of rising temperatures and effective responses from the international community.
- *Changing coastlines: effects of climate change*. Gives an overview of the issue of sea level rise and its impacts on coastal zones.
- *CO_2 mitigation and the Indian transport sector*. Deals with the growing demand for transportation, and the contribution of motorized road transport to climate change. It highlights the nature and magnitude of transport-related greenhouse gas emissions in India, and identifies possible approaches to mitigate them.

TERI would like to thank the Ford Foundation for providing the financial support that enabled the publication of this series of 'popular publications'. Thanks and appreciation go to Ms Preety Bhandari and Ms Sharmila Barathan for their contribution towards *How global is global and how warm is warming?* Dr Maria Ligia Noronha for *Changing coastlines: effects of climate change*, and Dr Ranjan K Bose for *CO_2 mitigation and the Indian transport sector*. Special thanks go to Dr Chandrasekhar Sinha for his comments and guidance, to Ms Preeti Soni for coordinating this endeavour, and to Ms Beena Menon for the production of this series.

R K Pachauri

Introduction

Historically, motorization [1] and the accompanying congestion, dependence on oil, and air pollution have plagued the large cities of the developed world. Today, however, motor vehicles and the adverse effects on their intensive use have spread worldwide. In the last two decades there has been a relentless growth in motor traffic, particularly that generated by cars. In many cities, especially those in the developing countries, the transport infrastructure has been unable to cope with this upsurge in traffic. Traffic congestion has become a common sight and a problem that the commuters have to put up with every day. Reduced vehicle travel speeds lead to longer travel time, extra fuel consumption, extra air pollutants, extra discomfort to road users, and degradation of the urban environment. To provide an efficient and environmentally-sound transport system is now a matter of great urgency in these cities, without which it would be difficult to achieve quality urban life for the inhabitants and to sustain economic growth.

The urban transport problem is fundamentally similar in all large cities. The basic causes are the same and so are many of the consequences, although there are some differences in degree between cities in developed and developing economies. Transport systems in large cities of the developing economies as compared to the developed economies are characterized by: (a) much lower levels of motorization of transport and travel requirement; (b) more rapid rates of economic growth, population growth, and the growth in number of motor vehicles; (c) higher population densities; (d) much lower per capita energy consumption and emissions of carbon dioxide; and (e) reduced access to capital and to advanced environmental technologies. Despite greater level of vehicle ownership, higher rate of trip generation, and increased use of energy on a per capita basis in cities of the developed countries, it is the large cities in the developing countries that, in general, suffer most from growing traffic congestion, road accidents, energy use and emissions, overcrowding of public transport, and poor conditions for pedestrians and cyclists.

A review of growing air pollution problems as a result of motorization in large urban agglomerations and the difficulties they face in finding solutions, can serve as a warning to other rapidly growing urban areas and a guide to how some of the problems can be tackled. A global assessment of urban transport air pollution is difficult, particularly in developing economies. Data sets on the pollutants and their health and environmental impacts are often nonexistent, incomplete, or out of date. There are also differences in methodology and reporting between countries and even within countries and cities.

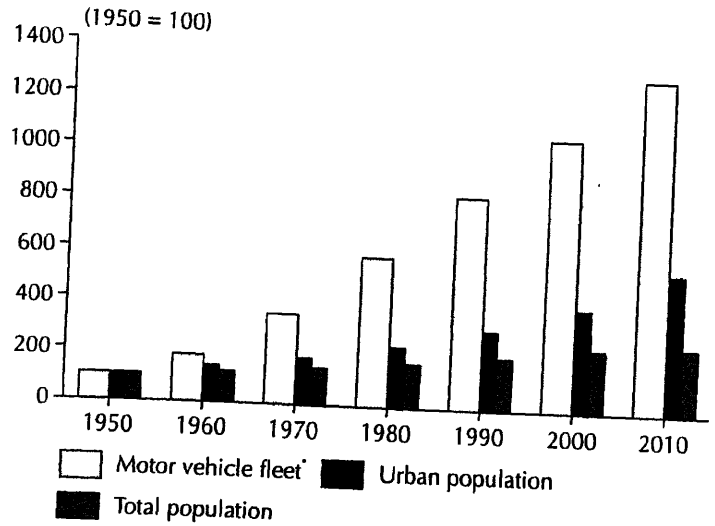
The paper presents a number of options to mitigate CO_2 (carbon dioxide) emissions from growing transportation demand in India. It is divided into four sections. The *first section* provides a comparative analysis of the growing transportation energy demand and the contribution of motorized road transport to air pollution, and the emissions of CO_2, between developed and developing economies; the *second section* gives an overview of the transport sector in India with particular reference to its growing dependence on petroleum products (i.e., gasoline and diesel) in large metropolises; *section three* gives the nature and magnitude of transport related CO_2 emissions in the country and provides the growing emissions of CO (carbon monoxide), HCs (hydrocarbons), NO_x (nitrogen oxides), SO_2 (sulphur dioxide), and other toxic substances such as TSP (total suspended particulate) and Pb (lead) from motorized transport. Finally, in *section four* possible methods of limiting CO_2 emissions of the transport sector in India are discussed.

Trends in motorization

Currently, the vehicle fleet is concentrated in the high-income economies of the world. In 1988, the OECD [2] (Organization for Economic Cooperation and Development) countries alone accounted for 80% of the world's cars, and 70% of the trucks and buses. The global population of motorized two- and three-wheeled vehicles (motorcycles, scooters, and auto rickshaws) is

not known, although they account for a substantial part of the motorized vehicle fleets in developing countries. In India, for example, two- and three-wheelers accounted for little over 70% of the registered motor vehicle fleet in 1992/93.[3] *Since 1950, the global vehicle fleet has grown tenfold and is expected to double within the next 20 years from the present total of 630 million vehicles.[4]* The rate of growth of the world's vehicle fleet is projected to surpass that of both the total and urban population. (See Figure 1).

Much of the expected rapid growth of motor vehicles is likely to occur in developing countries and Eastern Europe. For example, a tripling of the vehicle fleet is expected in China in the decade 1990 to 2000. Similarly, in India over twofold increase in vehicle fleet is expected during the same period—from 21 million to 43 million. In contrast, much of the demand for motor vehicles in the developed countries will be for vehicle replacement. As motor vehicle ownership approaches saturation levels in North America, Western Europe, and Japan, the maximum growth will be in developing countries and vehicle modes which have tended to get less attention such as two- and three-wheelers will become increasingly important. The dramatic increase in the growth of personalized vehicles is making unrestricted claims on valuable road space and petroleum products, on the one hand, while increasing congestion/air pollution, on the other.



*excluding two- and three-wheelers

Figure 1. Growth of population and motor vehicle numbers worldwide (1950/2010)
Source: Faiz A, *et al.* 1990

Two decades of transportation energy demand

Table 1 summarizes the commercial energy demand by different sectors, and by broad geographical/socio-economic regions worldwide for two years—1971 and 1990.[5] Currently, transportation accounts for about one quarter of the global commercial energy consumption, and for about 43% of oil consumption. Perhaps the most notable dynamic trend between 1971 and 1990 is the dominance of transportation energy consumption in the total demand growth in the OECD countries. During the same period, around two-thirds of the additional energy demand growth was a result of the increase in mobility levels. Based on the data presented in Table 1, Figure 2 reveals that while the share of energy use in transportation has declined in North America between 1971 and 1990 (from 48 to 39%), there has been a significant increase in developing countries (from 14 to 21%). During this same 20 year period, the highest average annual growth rate of transport energy demand has been observed in the developing countries (5.2%), and least in North America (1.6%). Consequently, while transportation energy demand was significant in both absolute and percentage terms, it accounted for only around 16% of the additional energy demand in developing economies.

Considering the differences in population growth in developed and developing economies and based on the data presented in Table 1, *the annual per capita energy consumption for mobility of goods and people varies from around 70 kgoe in developing countries to some 1900 kgoe in North America, i.e., by nearly a factor of 30.*[6] Thus, even though population growth rates are higher

Table 1. Final (commercial) energy demand by sector and world region, 1971 and 1990, in million tonnes oil equivalent and average annual growth rates (%)

Geographical regions	Commercial energy demand (mtoe)				Transport share out of total
	Industry	Trans-port	Residential & Com-mercial	Total	
1971					
OECD-North America	499	392	456	1347	29%
OECD-Europe & Pacific	518	199	336	1053	19%
Eastern Europe & ex-USSR	430	112	243	785	14%
Developing countries	145	110	312	567	19%
World	1592	813	1347	3752	22%
1990					
OECD-North America	542	526	461	1529	34%
OECD-Europe & Pacific	527	372	443	1342	28%
Eastern Europe & ex-USSR	577	167	420	1164	14%
Developing countries	681	287	702	1670	17%
World	2327	1351	2027	5705	24%
Average annual growth rate					
OECD-North America	0.44%	1.56%	0.06%	0.67%	74%
OECD-Europe & Pacific	0.09%	3.35%	1.47%	1.28%	60%
Eastern Europe & ex-USSR	1.56%	2.12%	2.92%	2.09%	15%
Developing countries	8.48%	5.18%	4.36%	5.85%	16%
World	2.02%	2.71%	2.17%	2.23%	28%

in developing countries, the much higher per capita consumption in developed economies ensures that they consume many times more energy than the developing ones.

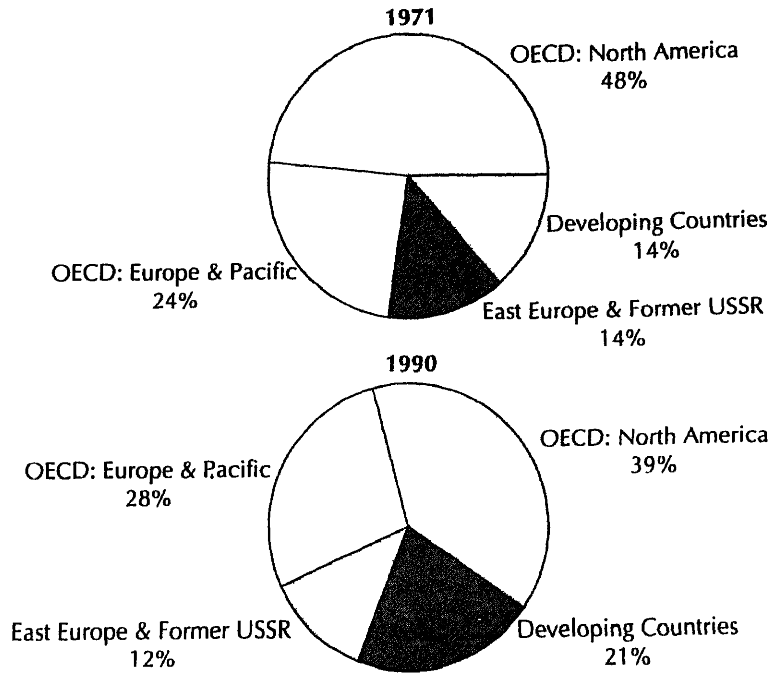


Figure 2. Changes in regional share of transport energy demand

Passenger transportation. The relationship between energy demand and passenger transport service requirements is more intricate than for goods transport. The main reason is the diversity of human activities resulting in mobility, and the complex nexus of values, preferences, and resulting lifestyle variables influencing mobility levels. These variables influence the transport modes chosen and the manner in which they are used. This can perhaps be best illustrated by analysing the different reasons for individual mobility in the United States (one of the countries with the highest mobility levels) and a developing country like India. People in the United States travelled some 6.7 trillion passenger-km in 1990, or some 26 900 km per capita, [7] as against 0.28 trillion passenger-km, or 333 km per capita in India during 1991.[8] It is perhaps surprising to note that less than 18% of all passenger-km in the United States are associated with com-

muting to and from the work place, whereas around 44% are associated with household and childcare business. In 1990, nearly 2.5 trillion passenger-km were travelled in the US for leisure purposes including vacations, and other social and recreational activities. Thus, leisure travel in the US is almost nine times the total travel of people in India although the latter has three times the population of the former. Further, public transport (buses and railways) in the developing countries (apart from their lower levels of per capita long-distance mobility) plays a dominant role in meeting travel demand instead of private automobiles in the OECD countries. Over time, in OECD countries, public transport has lost out to cars and air travel, implying that faster and energy intensive means of transport are preferred. For instance, more than four million cars were registered in the city of Los Angeles in the mid-1980s, with about 0.54 cars per inhabitant. [9] In such *automobile cities*, the market niche for public transportation is obviously rather small.

Congestion and emissions in urban areas

Motorization is inextricably linked to urbanization. Mobility in urban areas is of particular interest, because limits of space and high densities of land-intensive individual transport modes (cars, two- and three-wheelers) result in congestion. The world population is expected to increase from 4.8 billion in 1985 to over 6.0 billion in 2000. What is more significant is that almost one-half of the world's population will be living in urban areas by the end of this century. The growth in urbanization would be most pronounced in Africa, South Asia, and Latin America. The concentration of population in very large conurbations has led to some of the world's worst congestion, air pollution problems and has had damaging impact on the global environment.

Transport and air pollution. Mobile sources, particularly motor vehicles, are a major cause of air pollution. Motor vehicles emit CO, HCs, NO_x, SO_2, and other toxic substances such as TSP and Pb. Emission rates of CO and HCs from diesel vehicles are lower than that of gasoline vehicles because of better combustion efficiencies. While the emission rate of NO_x is higher in diesel vehicles because of lower combustion temperatures. Diesel vehicles emit TSP and higher levels of SO_2 but not Pb. The growing vehicle population is a major contributor to air pollution problems. Initially, these problems were most apparent in city centres but over the last two decades lakes and streams and even remote forests have experienced significant degradation. As evidence of anthropogenic impacts on the upper atmosphere accumulates, there is increasing concern about the part played by motor vehicles in global warming.

Motor vehicles constitute the main source of air pollution in most of the cities in the developing countries. This is particularly true of the CO, NO_x, and to a lesser extent, SPM, HCs, SO_2 emissions into the atmosphere. Even regions, where cars are equipped with catalytic convertors (like Los Angeles) are plagued by smog, primarily ozone (O_3) formed by the photochemical reaction of two motor vehicle exhaust emissions—NO_x and VOCs (volatile organic compounds). The cities of developing countries, in contrast, exhibit a greater variety of air pollution sources. The relative contributions of mobile and stationary sources to air pollutant emissions differ markedly among cities and depend on the level of motorization and the level, density, and type of industry present. However, in the cities of developing countries, vehicles are a significant source of air borne toxic pollutants, accounting for up to 95% of Pb. [10]

Four factors make pollution from vehicles more serious in developing countries. First, many vehicles are in poor condition, creating more particulates and burning fuels inefficiently. Certain types of engines, such as two strokes, are particularly bad, though new options for improving their efficiency may be available soon. The two stroke engines emit hydrocarbons and smoke up to 10 times the rate of modern four stroke engines and produce the vast majority of the emissions. Second, lower quality of fuels are used, leading to the emissions of far greater quantities of

pollutants. Third, motor vehicles are concentrated in a few large cities. Fourth, a far larger percentage of the population moves and lives in the open, and is thus exposed to automotive pollutants.

Transport and global environment. The transport sector has a deleterious effect on the global environment. Products of combustion emitted from vehicles produce about one-fifth of CO_2 (which contributes to global warming), one-third of CFC's (which contribute to ozone depletion) and one-half of NO_x (which contribute to continental scale acidification and ecological damage). The transport contribution to ozone depletion is now being reduced by the elimination of fully halogenated CFCs. [11] The same is not true of global warming gases. Moreover, while global warming is at present primarily a result of the industrialization and motorization levels in OECD-countries, it is likely that by the year 2010, the developing countries will be primarily responsible for CO_2 emissions (See Figure 3).[12]

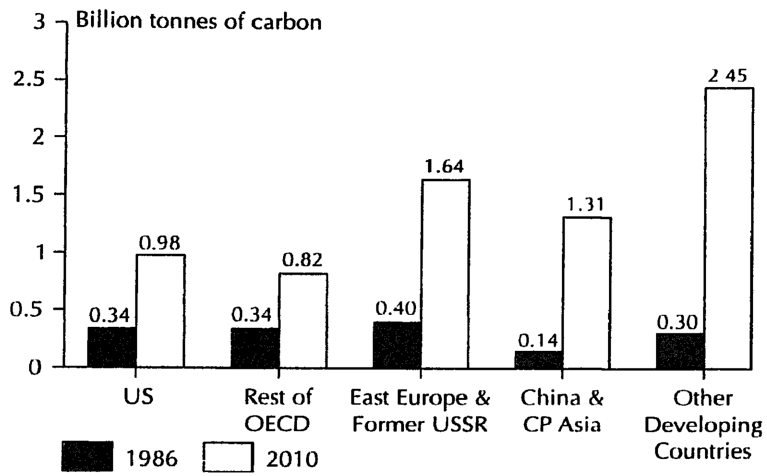


Figure 3. CO_2 emissions in a rapidly changing world scenario

Environmental impacts differ significantly by mode of transport. Road motor vehicles are the dominant source of emissions which have local and continental impacts. Rail transport is a relatively benign mode of land transport.

The scale of emissions from transport. The transportation sector currently accounts for approximately 22% of global final energy consumption and emits more than 1 Gt (giga tonne) of carbon annually, which is about 16% of the total emissions and around 40% of the liquid fuel emissions. [13] Carbon emissions in the transportation sector are dominated by the Northern countries with their high levels of private mobility and material consumption (i.e., goods transport requirements). About two-thirds of the transport carbon emissions originate in the OECD region. By far the largest single source of carbon emissions is the worldwide fleet of over 400 million passenger cars, emitting approximately 0.5 Gt of carbon.

A comprehensive assessment of the nature and magnitude of transport-induced air pollution in developing countries is precluded by the complexity of the contributory factors and lack of reliable information. A case by case assessment is required based on detailed emission inventories and air quality monitoring programmes. But it can be stated with certainty that:

- the contribution of transport to air pollution in developing countries will increase substantially with the projected growth in motorization; and
- transport air pollution in developing countries is largely an urban phenomenon confined mainly to very large cities with a high proportion of trips by buses, automobiles, motorcycles, and other two- and three-wheeled vehicles.

Transport scene in India

In India, the share of the transport sector to total GDP in 1993/94 was about 4.8% (Rs 111.2 billion at 1980/81 prices). [14]

The gross value added by the transport sector grew by 7.5% per annum between 1980/81 and 1993/94. That transport services have grown, reflects not only a growth in economic activity, but also an increase in mobility of individuals.

In 1980/81, the railways and road transport together accounted for 73% of the total GDP contribution by the transport sector. This share went up to about 80% in 1992/93, contributed primarily by the road transport sector. Since, in the transport sector, the per unit of GDP generated (in terms of movement of man and material) is 4 to 5 times more energy intensive than rail transport, this implies that in terms of relative contribution to GDP the country is moving towards a more intensive use of the modes of transport.

Infrastructure

The transport infrastructure has expanded considerably in terms of network and services over the last four decades. Railways have extended their route length from 53 596 km in 1950/51 to 62 571 km in 1991/92.[15] Freight in tonne km, carried by the railways has increased almost six-fold during the same period. Passenger traffic has grown by three times between 1950/51 and 1991/92. Travel demand has increased four-fold from 66 517 million passenger-km to about 2 80 848 million passenger-km during the same period. The aggregate length of roads has increased from 0.4 million km in 1950/51 to 2.3 million km in 1991/92. Forty six percent of the villages in the country are now connected by all-weather roads. Traffic handled by the major ports has increased nearly seven-fold in the last four decades. The number of buses has gone up nearly eleven-fold and goods vehicle fleet by twenty-fold. Domestic air traffic has increased ten-fold in the last 30 years.

Railways

The railways' share of both freight and passenger traffic has decreased since the early sixties. This may be due to the relative decline in the railways' share of public sector expenditure, when the share of traffic handled by road increased rapidly. Road transport grew also because, in addition to public investment, there has been considerable private investment in it as well; this is evident from the private ownership of cars, taxis, two-three-wheelers, trucks, and other vehicles.

There has been a steady decline in the overall energy consumption intensity of the rail transport system since 1970/71, solely because of the major switch in locomotive power, from energy intensive coal to diesel and electricity (intensity of steam locomotion in fact increased as steam engines began to be used increasingly for short haul movements, with several halts). The number of coal using steam locomotives has reduced substantially, even as the stock of diesel and electric locomotives increased. It is, therefore, clear that once all steam locomotives are phased out, further overall improvements may be possible only through design improvements and/or better management.

Road transport

The total road network in the country increased by about 21% from 1.69 million km in 1985 to 2.04 million km at the end of 1990/91. The National Highways constitute hardly two per cent of the total road network but carry nearly 40% of the total traffic. The total length of national highways has increased by no more than 72% between 1950/51 and 1990/91, while the increase in the case of all other roads is of the order of 536%.

The present share of road traffic is about 80% in passenger traffic and about 50% in freight traffic compared to all other modes. During the last four decades, road transport has rapidly gained importance in the overall transport system of the country. As shown in Figure 4, the total number of mechanized motor vehicles in the country increased by more than 11 times between 1971/72 and 1991/92 (from 1.9 million to about 21.3 million). [16] The country had 25.3 million registered vehicles during 1992/93.

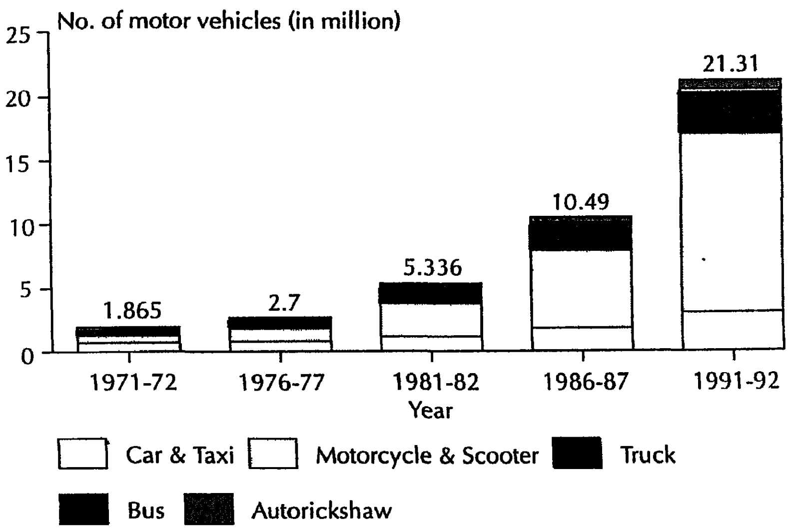


Figure 4. Vehicle growth and its composition in India

Road transport passenger services are provided both by the public and private sector in the country. While the total number of passenger buses is estimated to have increased from 0.15 million in March 1981 to 0.38 million in March 1993, the share of the public sector buses in the country as a whole has declined from 45% to around 33%. The private vehicle population in India between March 1985 and March 1993 has grown about 15% per annum (from 6.7 million to 20.1 million). In most major urban centres the private modes of transport will constitute the predominant transport system in the foreseeable future with consequent problems of congestion, higher energy consumption, and heavy atmospheric pollution.

The number of goods vehicles registered at the end of the March 1993 was about two million. Credit scarcity and rising input costs have adversely affected the performance of private transport operators. Road freight services are almost wholly owned and operated by the private sector. Steps have been taken in recent years to remove certain impediments in the path of the road transport industry. A major step has been to liberalize the issue of national and zonal permits.

Vater transport

Both inland water transport and coastal shipping have played a limited role in India. Among the most important constraints is the vintage of existing fleet of tugboats, barges, tankers, and other vessels. The database on water transport, from published sources, leaves much to be desired. Data on freight tonne-km is not available.

Air transport

Air traffic in India has grown rapidly since the early seventies. The overall energy intensity of Indian Airlines has reduced. According to an estimate made by the Indian Airlines, the intensity reduced from 0.083 litres of ATF (Aviation and Turbine Fuel) per available seat-km in 1970/71 to about 0.049 litres per seat available seat-km in 1982/83.

Transport energy demand. The transport sector in India is a major energy-consuming sector, particularly of oil (See Figure 5). About half of the total petroleum products consumption (i.e., 60.4 million tonnes of oil equivalent) in the country went into the transport sector in the form of HSD (high speed diesel) and gasoline during 1993/94.[17]

Energy consumption in the transport sector has increased at the rate of 3.1% per annum between 1970/71 and 1980/81. It grew at a much faster rate of 4.9% between 1980/81 and 1990/91. Higher rate of growth of energy consumption in the latter period is primarily because of two structural shifts that occurred in the transport sector. The first is the decrease in the share of both freight and passenger movement by rail. The second is increase

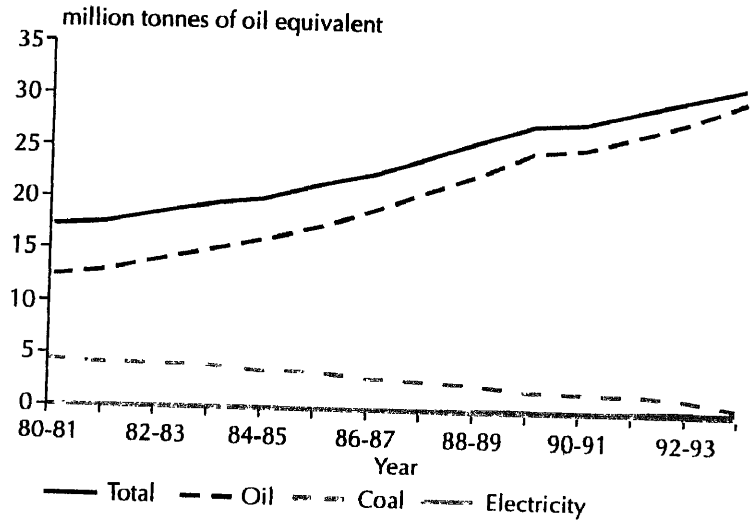


Figure 5. Transport energy demand in India, 1980/81 to 1993/94

in the share of personalized modes of transport of passenger traffic. For instance, the share of motorized road transport in passenger traffic increased from 67% in 1970/71 to 78% in 1987/88. Again in freight traffic, the share of road transport increased from 34 to 51% over the same period. There has also been a gradual shift from coal to oil as the main fuel in the transport sector. While the share of coal in the total transport energy demand declined from about 27% in 1980/81 to less than 1% in 1993/94, the share of oil has increased from about 72 to 96%. The share of electricity use in transport is insignificant, but increased marginally from 1.1% in 1980/81 to 1.5% in 1990/91. This is on account of greater dependence on road transport *vis-a-vis* railways and a shift away from steam traction to diesel and electric traction.

It is essential to reverse these trends if the rate of growth of energy consumption is to be no more than the rate of growth of transport services. This would suggest increased rail track length, higher efficiency and faster movement in the railways, and enhanced public transport systems. If these steps are taken there is a possibility of reversing the high rate of energy consumption growth in the transport sector.

Urbanization, motorization, and pollution. There is a direct relationship between transport energy consumption and the level of emission of pollutants from transport sources. This relationship also offers the simplest approach to control transport emissions, reduced consumption of fossil fuels and increased efficiency in transport energy use.

Much of the air pollution problems in the country are restricted to the urban areas, where automobiles are the major contributors. Rapid urbanization, especially around larger cities, has created acute problems of transport. The pattern of transportation in urban centre differs; it is determined by factors such as size of the city, the employment characteristics, industrialization, commercial growth, topography, and the urban form and structure of the city. In view of the large number of cities in India and the prevalent socio-economic environment, the road-based systems will continue to play an important role in the movement of passengers and freight in cities of all sizes. The increase in income level, inadequate provision of public transport services, unconstrained expansion of cities and the minimal importance of non-motorized vehicles in urban areas, have given rise to a phenomenal growth in the number of private vehicles (at the rate of 16% per annum during the last decade). In most major urban centres such private modes will continue to dominate the transport system in the foreseeable future with consequent problems of congestion, higher costs, inefficient energy consumption and severe atmospheric pollution. Traffic speeds are also falling, leading to increased energy consumption and emissions.

Urbanization trends. The pace of urbanization in India has been increasing, especially in the last four decades. In 1951, the urban population was 62 million (17.3% of the total). By 1991, this number

had swelled to nearly 217 million, with one in every four persons living in the urban areas. [18] It is expected that by the year 2001, India's population will near the one billion mark and nearly one-third of this population (326 million) will be in urban areas.

There is a skewness of distribution of population among different urban centres with a high concentration of the population in a few large cities. Indian census categorizes urban population into six classes of cities/towns. Urban growth has mainly occurred in cities with over 100 000 people (i.e., class I cities). Such a trend in class I cities gives continuity to the pattern of urbanization that has taken place in India since 1901 (See Figure 6). Over 65% of country's urban population lives in these large cities. The growth in the number of medium size towns has not kept pace with the growth in urban population. The share of class II (each with 50 000 to 99 000 people) and class III (each with 20 000 to 49 999 people) in the total population has remained more or less steady. Medium towns account for 24% of the urban population. The share of small size towns: class IV (each with 10 000 to 19 999 people); class V (each with 5000 to 9999 people); and class VI (each less than 5000 people), show a steady decline.

Growth in metropolitan cities

According to the 1991 census, there are 23 metropolitan cities (each with over one million people) in the country. The total population of these metro cities accounts for nearly one-third of the total urban population and one-twelfth of the total population. Over 50% of the population of these metropolitan cities lives in the five giant metropolises of Greater Bombay (12.57 million), Calcutta (10.92 million), Delhi (8.38 million), Madras (5.36 million), and Bangalore (4.09 million). Among these metropolises, the highest decadal growth rate is recorded by Greater Bombay (53%), while the lowest growth rate is recorded by Calcutta (19%). However, in terms of the average population density, Calcutta had the highest figure of 23 669 persons/km^2

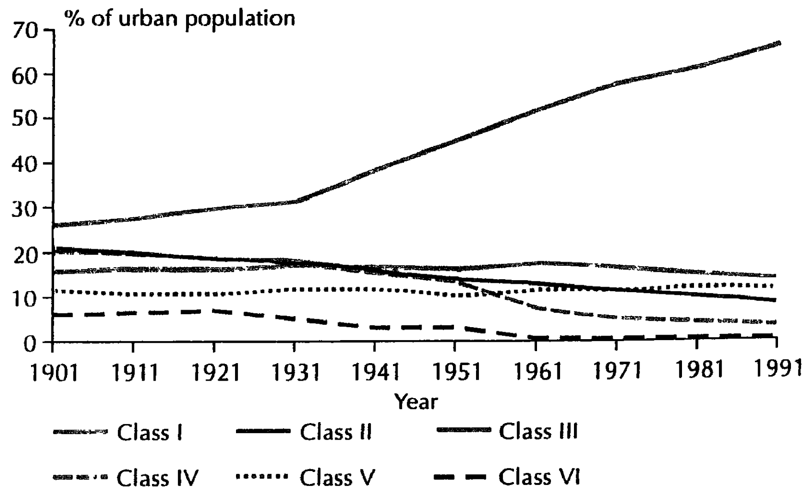


Figure 6. Urban population by size class, 1901/1991

during 1991 followed by Madras (21 811), Greater Bombay (16 434), Bangalore (14 387) and Delhi (14 313). Due to inadequate land supply to meet the growing population, the density of population in these cities is likely to increase further causing undue stress on the pubic transport systems.

Growth of motor vehicles

In 1992/93, the metropolitan cities accounted for about one-third of the total 25.2 million vehicles in the country. About 47% of the total cars in the country are confined to these metropolitan cities (See Figure 7). The corresponding figures for other vehicular modes are shown in Figure 7. The five giant metropolises, namely, Bombay, Calcutta, Delhi, Madras, and Bangalore accounted for over 38% of the cars in 1992/93, 17% of the two-wheelers, 21% of the three-wheelers, 15% of the buses but only 6% of the goods vehicles (See Figure 7). Delhi has registered the largest vehicle population (2.1 million in 1992/93) which is more

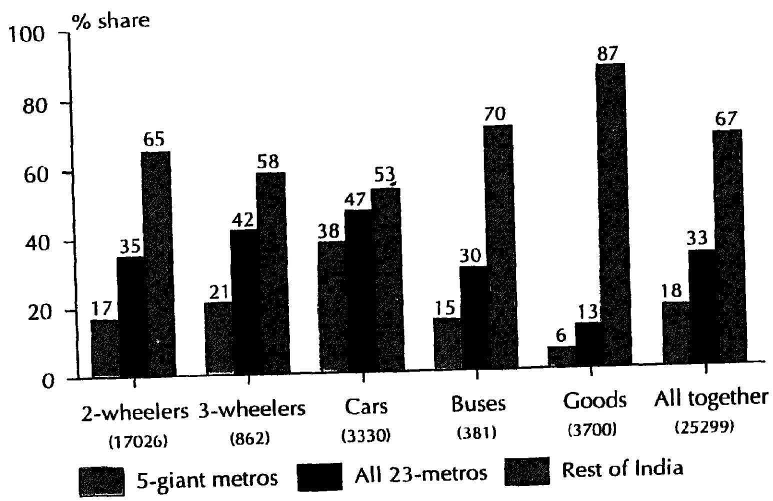


Figure 7. Vehicle composition in cities, 1992/93
Note: Figures in brackets are total vehicles in thousands

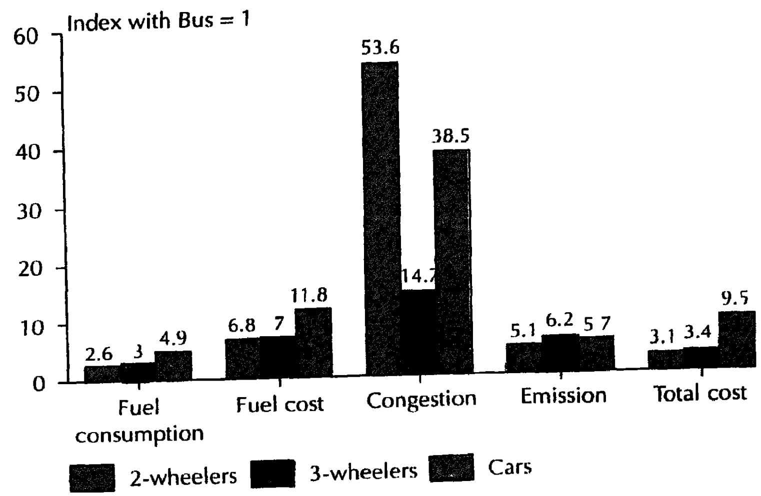


Figure 8. Implications of alternate modes compared with bus

than the total number of vehicles in Bombay, Calcutta, and Madras taken together (1.8 million).

The growth in ownership and use of motorized vehicles in the metropolitan cities has been faster than the population. One noticeable feature about growth in motor vehicles is the explosion in the number of two-wheelers, three-wheelers, and cars. Between 1986/87 and 1992/93, the annual rate of growth of two-wheelers in the country has been over 14%, three-wheeler 12%, and passenger cars 9%, respectively. The growth rate of buses (7.5% per year over this period) is lagging behind the growth rate of private vehicles, leading to road chaos, congestion, inefficient fuel utilization, and growing levels of emissions in the atmosphere.

The present industrial policy of the Government with regard to transportation equipment is lopsided due to the greater emphasis on production of cars and two-wheelers rather than buses. Car and two-wheeler production has gone up by over six per cent and eight per cent per annum, while the growth rate of bus production was less than one per cent between 1986/87 and 1990/91.

Advantages of mass transport

Figure 8 gives a comparative analysis of energy-economic-environmental implications of the use of alternate transportation modes compared with the bus, to meet each passenger kilometre of travel demand. Figure 8 reveals:

- a car consumes nearly five times more energy than a bus, while two-wheelers consume about 2.6 times and three-wheelers three times;
- a car occupies over 38 times more road space in comparison to a bus. The corresponding figures for two-wheelers and three-wheelers are 54 and 15 respectively;

- the fuel cost of two-wheelers is 6.8 times, three-wheeler 7 times, and car 11.8 times, when compared to a bus. While the total cost of operation of two- and three-wheelers is over three times and car 9.5 times higher than the bus; and
- a similar advantage of bus is observed when mass emissions of CO, HCs, NO_x, and TSP are considered. A three-wheeler emits 6.2 times, car 5.7 times, and two-wheeler 5.1 times more than a bus.

This suggests that mass transportation is vastly superior to the use of personalized vehicles. The desirable cost-effective solution to move people with fewer vehicles using less energy and less pollution could be achieved by increasing the share of mass transport based on buses.

Carbon dioxide emissions in India

National CO_2 emissions

Global CO_2 emissions from fossil fuel (in the form of solid, liquid, and natural gas) consumption, cement manufacturing, and gas flaring have risen significantly since 1950/51. India, like other countries of the world, is largely dependent for its energy on fossil fuels. India occupies the sixth place as a national contributor. Total emissions increased by 10.4 times over this period, from 18.4 TgC (tera gram of carbon) in 1950/51 to 192 TgC in 1991/92), and per capita emissions increased almost 4.4 times (from 0.05 TgC to 0.22 TgC). Per capita emissions in 1990/91 were approximately four per cent of the Unites States value. Figure 9 shows the CO_2 emissions trend from the use of different forms of energy in the country between 1980/81 and 1991/92.

At present, coal accounts for about 60% of fossil fuel use in calorific terms, followed by liquid petroleum, about 30%, and the rest natural gas. CO_2 emissions result largely from coal burning. Coal contributed about 87% of the emissions in 1950 and 71% in 1991; at the same time, the petroleum fraction increased from 11 to 22% (See Table 2).[19]

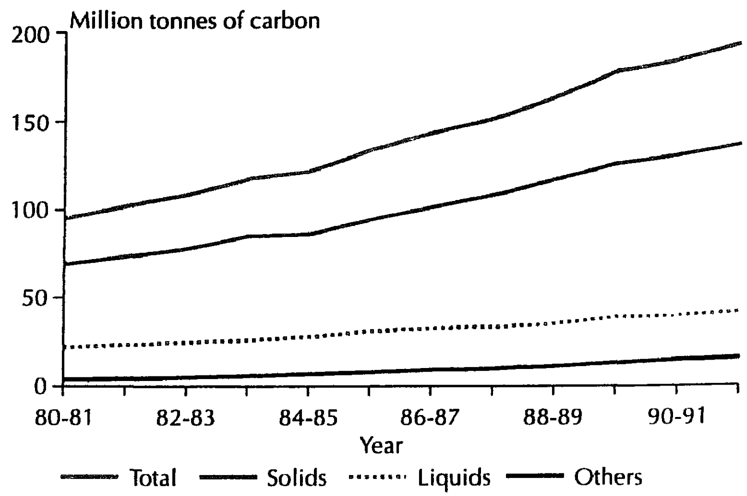


Figure 9. CO_2 emissions from India

CO_2 emissions from petroleum use in transport sector CO_2 emissions from gasoline and diesel consumption in the transport sector is computed by taking their percentage of carbon content values. The carbon content of Indian gasoline is 84.85%, while that of HSD 86.11%.[20] Not all carbon is oxidized during the combustion of these liquid fuels.

Table 2. Relative emissions from coal, petroleum, and natural gas in TgC/year

Year	Coal	Petroleum	Natural gas	Cement and gas flaring
1950/51	16.0 (87%)	2.0 (11%)	0.0 (-)	0 4 (2%)
1960/61	26.8 (81%)	5 3 (16%)	0 0 (-)	1 1 (3%)
1970/71	37.7 (71%)	13 1 (24%)	0 3 (1%)	2.2 (4%)
1980/81	69 7 (73%)	22.4 (23%)	0 7 (1%)	2 7 (3%)
1990/91	130.1 (71%)	39 6 (22%)	5 2 (2%)	9 4 (5%)

Gasoline is only used in automobiles such as passenger cars and two- or three-wheelers. A ratio of 2:3 distribution of gasoline is considered between passenger cars (4-stroke engines) and two-three-wheelers (2-stroke engines). The unburnt fuel in these cases is assumed to be 2 and 25%, respectively. Diesel to the extent of 90% is consumed by the transport sector for vehicles such as buses and trucks, and by the railways. The remaining 10% is used in agriculture for lift irrigation and for miscellaneous uses, largely for power generation through small diesel generating sets. [21] A flat one per cent of unburnt fuel is assumed for diesel engines.

Figure 10 presents CO_2 emissions from the use of petroleum products in the transport sector for the period 1980/81 to 1995/96. Total CO_2 emissions increased at the rate of 7.5% per year over this 15 year period, from 8.8 to 26.2 TgC. About 42% of the liquid fuel emissions in India was from use of HSD in the transport sector during 1990/91. The corresponding figure from gasoline is little over six per cent.

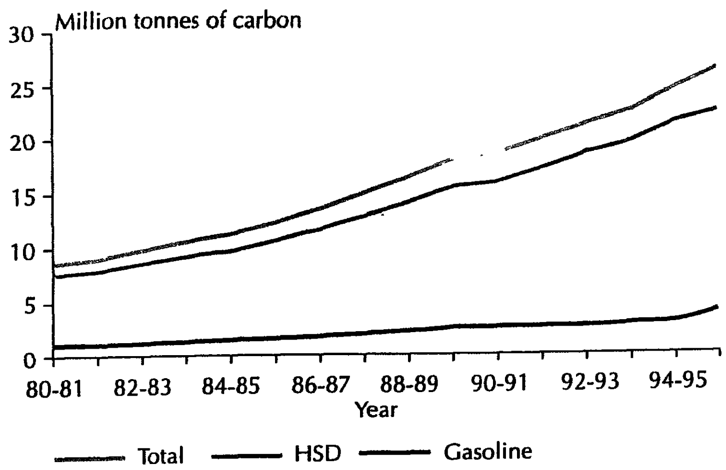


Figure 10. CO_2 emissions from transport (only petroleum products)

Air pollution from road transport sector and CO_2 emissions

National. Apart from CO_2, substantial amounts of other pollutants such as TSP, HCs, NO_x, and CO are also emitted by the road transport sector. RRI (Road Research Institute), India, has estimated emission of these pollutants (See Table 3).[22] As can be observed from Table 3, emissions of all these pollutants has more than doubled during the decade of the 1980s. Some of these pollutants chemically transform in the atmosphere and produce secondary pollutants causing warming of the atmosphere through OH quenching. These pollutants also impair local air quality.

Metropolitan cities. Of the total 23 metropolitan cities in the country, road-based CO_2 emissions were computed for the top 12 metropolises (See Figure 11).[23] Delhi was responsible for the maximum CO_2 emissions (about 663 thousand tonnes of carbon in 1991), and also the highest per capita emissions (0.08 tonnes/year). It is interesting to note from Figure 11 that some of the giant cities like Bombay and Calcutta, in spite of higher annual

Table 3. Road transport pollutant emissions in India ('000 tonnes/year)

Year	TSP	NO_x	HC	CO	CO_2 (in C equivalent)
1980/81	20.4	96	41	889	6329
1981/82	21.4	100	43	933	6630
1982/83	23.6	111	47	1015	7319
1983/84	24.9	117	50	1097	7732
1984/85	27.2	128	55	1203	8424
1985/86	29.5	138	60	1311	9162
1986/87	31.9	146	65	1431	9892
1987/88	35.3	165	73	1597	10940
1988/89	37.7	176	78	1722	11686
1989/90	41.8	195	89	1947	12958

emissions, have lower per capita CO_2 emissions, than some medium size metro cities, like Ahmedabad, Pune, and Jaipur. This is due to inadequate mass transport facilities in these medium size cities, resulting in higher dependence on personalized vehicles which are relatively energy intensive compared to mass transport.

CO_2 mitigation options for the transport sector in India

Policies that can help reduce CO_2 emissions by the transport sector are given below.

- Improving energy efficiency
- Behavioural change
- Enhanced public transport system
- Mass rapid transit systems in giant metropolises
- Capacity augmentation of rail tracks
- Technological change

Efficiency improvements

Today, the most-fuel efficient car available on the Indian market is about twice as fuel efficient as the current fleet average. Models such as the Maruti Zen, Maruti Standard (800cc) have an average gasoline consumption of less than 5 litres/100 vehicle-km. This represents an improvement over current fleet averages by a factor of two. Similarly, the most-fuel efficient two-wheelers (scooters and motorcycles) like Hero Honda (100cc bike), with an average gasoline consumption of less than 2 litres/100 vehicle-km, are as much as one and a half times more efficient than other motor bikes on the road.

The buses with the best current designs consume 20 litres/100 vehicle-km, as against the traditional ones (28 litres/vehicle-km). In India, these are modelled around a truck chassis which is basically designed for long-distance inter-city traffic. Buses need to be designed specifically for intra-city traffic.

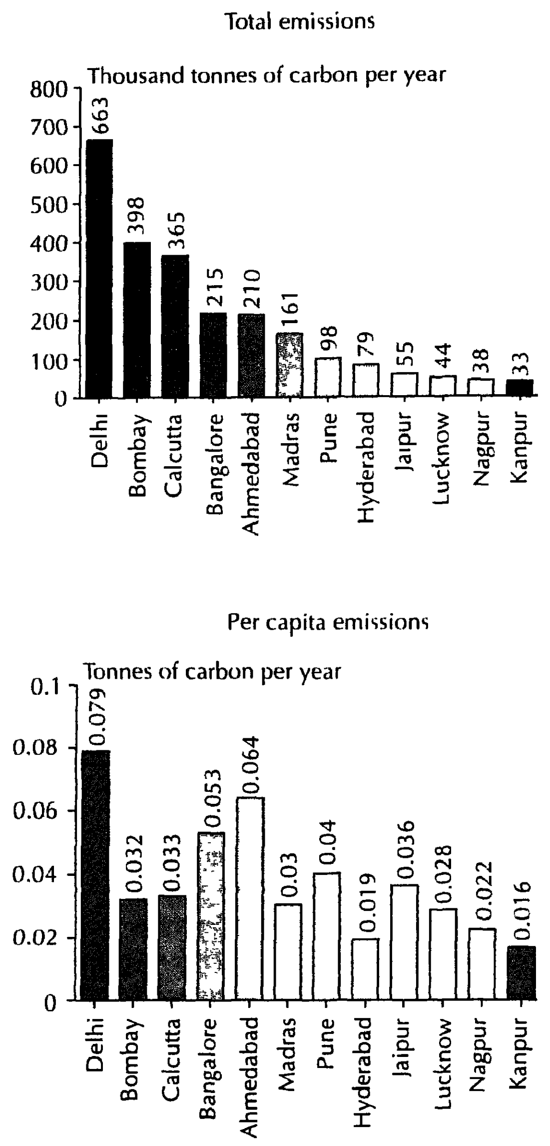


Figure 11. Road transport CO_2 emissions from cities, 1991

Measures to increase system efficiency also include improvements in traffic flow thereby increasing fuel efficiency by:

- improved traffic regulation systems and enforcement of traffic rules;
- grade separation of fast and slow traffic, where possible;
- exclusive busways at least along the main arterial city roads;
- well designed arterial road intersections;
- proper designed and maintained sidewalks, and pedestrian crossings; and
- removal of encroachments on pavements and roads.

The congestion on some of the roads in the CBDs (central business districts) can be relieved by:

- restraint on the parking of cars and two-wheelers in congested areas;
- area licensing fees, for low occupancy vehicles entering congested areas; and
- introduction of car free zones on arterial roads in CBD where only public carrier vehicles would be allowed to operate.

Estimates of carbon reduction potential and costs of CO_2 emissions in the transportation sector are difficult to determine at the national level. However, from a few representative studies, estimates of reduction potentials worldwide indicate that current carbon emissions in the transportation sector could be reduced by one-third. [24, 25] The cost estimates of carbon reduction vary significantly across countries. For instance, in Brazil, 15% of the carbon reduction in the transport sector could be achieved at negative or zero specific reduction costs (also termed as no regrets option). The corresponding figures for member states of European Communities and USA are 18 and 21% respectively.

Most of the measures analysed in the national studies discussed above focus on fuel efficiency measures. Investments in the improvement of infrastructure to increase energy efficiency appear costly as a carbon reduction strategy (more than $1000 per tonne of carbon), but the main benefit (and rationale) of such investments is in fact not so much in reducing emissions but in improving the quality of transportation services. [26]

On the demand side, the Mitigation Panel estimated that a doubling of gasoline prices in the United States would induce consumers to prefer cars that are between 12 and 15% more energy efficient. [27] The freight sector is expected to be more sensitive to such price signals. Still, even there, long-run elasticities are not dramatic.

It thus appears that price signals, especially in a typically acceptable range, will not lead to dramatic reductions in transportation fuel demands. This points to the need to investigate regulatory approaches such as mandatory efficiency standards and consumer information programmes to realize more fully the CO_2 reduction possible or potential fuel efficiency improvements.

Behavioural Change

Behavioural change not only influences *what* transport modes are chosen, but also *how* they are used (usage efficiency). *Usage efficiency* comprises many components, ranging from traffic flow (congestion), driving modes and styles, and most importantly, load factors. For instance, the average occupancy rates for Indian commuters are estimated to be below three persons per car while that in cities the occupancy level is much lower. This means more energy use and emissions per passenger-km driven.

Usage efficiency is perhaps the least understood factor that could improve the efficiency of transportation systems. An improvement in it will involve not only changes in social behaviour and trip organization (such as car pooling or car sharing), but also in public policy incentives, such as the provision of special driving (high occupancy vehicle) lanes or toll reductions for car pools (as practised in some US cities), or parking fees or city entrance fees (introduced in some European and Asian cities).

Facilitating the shift from personal to public transport

A reliable forecast for total urban transport demand has been made by the Study Group on Alternative Systems of Urban

Transport set up by the Government of India. [28] According to this study, there will be 83 cities in India of different sizes, each with populations above 0.25 million, during 2001. As given in Table 4, the total estimated travel demand in these 83 cities will be 443 BPKM (billion passenger kilometres). Nearly 20% of the total travel demand will be met by suburban and urban rail traffic systems, while the remaining passenger travel demand will be met by road transport.

Road transport. To quantify the advantages of enhanced use of public transport, the Study Group has considered two scenarios: (i) BAU (business-as-usual) [29], and (ii) increased share of buses. In the BAU scenario, the total travel demand in 2001 to be catered by bus would be 57%, and that of cars 9%. In the alternative scenario, the share of buses would increase from 57 to 80%, while that of cars would decrease (from 9 to 4%). The balance trips to meet the total travel demand is split in the ratio 2:1 between two- and three-wheelers in both the scenarios. Overall, the aim is to reduce work trips by personalized modes of transport and divert the traffic to buses.

Table 4. Projections of urban travel demand for 2001

Population range (million)	Median population	Number of cities	Population (million)	Travel demand (BPKM/year)
over 8	13	4	52.0	314.5
3–8	6	3	18.0	59.8
-4	3	4	12.0	25.9
1–2	1.5	15	22.5	25.6
0.5–1	0.750	36	27.0	15.6
0.25–0.5	0.375	21	7.9	1.4
Total		83	124.4	442.8

As given in Table 5, an increase in the share of bus travel from 57 to 80% leads to a saving of 1.1 million tonnes of oil in the 83 cities taken together. The other advantages are: 54% reduction in the number of vehicles on the road; 36% reduction in air pollution, 27% reduction in CO_2 emissions; and 33% reduction in aggregate road transport costs. The increase in the number of buses required in the recommended scenario is 25 000 buses implying an additional investment of Rs 16 250 million (considering cost of a bus to be Rs 0.65 million at 1994/95 prices). With

Table 5. Implications of shift to buses

	Unit	As per present trends					As per alternative scenario				
		Bus	Car	2-wh	3-wh	Total	Bus	Car	2-wh	3-wh	Total
Total travel demand	10^9 PKM	205	33	80	40	358	288	14	36	20	358
Modal Split	%	57	9	22	12	100	80	4	10	6	100
Number of vehicles	10^3	62	1173	7809	532	9576	87	488	3542	260	4377
Passenger Car Units	10^3 PCUs	186	1173	3904	532	5795	261	488	1771	260	2780
Fuel demand	10^3 toe	1270	1012	1277	733	4292	1786	421	579	359	3145
Air pollution loading	10^3 t	389	361	766	463	1979	547	150	347	227	1271
CO_2 emissions	10^3 tc	1077	860	1086	623	3646	1518	358	492	305	2673
Cost (at 1994–95 price)	10^6 Rs	56091	87216	68093	37134	248535	78916	36288	30893	18194	164290

about 40% of the investments required in infrastructure development, the required investment would be about Rs 22 825 million (US $727 million at 1994/95 prices) up to the turn of the century. Assuming an average lifetime of 10 years, the total reduction in CO_2 emissions is 9.35 tc, at the specific cost of Rs 2346 (US $74.71) for reducing one tonne of carbon.

The split of different modes of transport suggested above is feasible if an imaginative policy for bus transportation providing for different types of services, like express, deluxe, etc. to cater to different interests, is implemented to wean away commuters from personalized transport to buses. A change in industrial policy in the automotive sector would also be needed. There have to be an accelerated production of fuel-efficient buses designed specifically for urban transport and a cutback on production of cars and two- and three-wheelers.

Rail transport

In India only three giant cities—Bombay, Calcutta, and Madras—have an urban rail transport system. This is expected to provide a capacity of little over 80 BPKM by the turn of the century. Urban rail transport systems consume less energy as compared to motorized road transport, and hence CO_2 emissions are curbed.

To meet the complex and ever growing transportation requirements in the giant metropolises, an integrated MRTS (Mass Rapid Transit System) is recommended by the experts. The major barrier to MRTS in different cities is the enormous funds required. For instance, in Calcutta, an eight km lengthening of the 16 km long existing metro would need about rupees five billion. [30] A MRTS in Delhi would cost about Rs 100 billion.[31] However, the benefits accruing from the reduction of CO_2 emissions provide the justification for the MRTS.

The proposed multi-modal MRTS scheme in Delhi has three components. These include existing ring rail corridors (144 km), an elevated Light Rail Transit System (24 km East-West direction and 17 km North-South direction), and a high capacity bus system (12 km from Patel Nagar to Papankala).

The global environmental benefits (in terms of reduction in CO_2 emissions) due to implementation of MRTS in Delhi can be justified on the ground of incremental costs of CO_2 saved. According to a study [32], the total reduction in CO_2 over 35 years (assumed life of an MRTS) is estimated to be about 14 tc. The incremental costs for this saving is attributed to:

(a) construction and implementation of MRTS. It would cost about Rs 82.16 billion at 1994/95 price; [33]

(b) operation and maintenance. It accumulates to Rs 145.94 billion in 35 years; and

(c) electricity generation cost for MRTS. It is estimated that about 51 MW of power would be required for MRTS. The associated costs are:
- installation cost @ Rs 35 million/MW = Rs 1.79 billion;
- operation and maintenance @ 2.5% of installation cost = Rs 1.56 billion over 35 years; and
- fuel cost @ Rs 700 per kg of coal = Rs 5.53 billion over 35 years (1 kWh requires 0.68 kg of coal).

Hence, the total cost would become Rs 236.98 billion (US $7.64). The government would save the funds that would be invested in buses due to the introduction of the MRTS. The annual savings due to capital, replacement, and operation of buses are estimated to be about Rs 230.93 billion (US $7.45 billion) over 35 years.

Thus, the incremental cost per tonne of CO_2 saved is given by, (cost incurred – saving in public sector) divided by the total CO_2 reduction. This would translate into Rs 432.14 (US $13.94) per tonne of CO_2 saved in carbon equivalent.

Generally, the projects which find favour with GEF (Global Environment Facility) for funding, low risk projects, under high country priority in the transport sector, are found to have the incremental costs per tonne of CO_2 removal of not more than US $10 (or US $37 per tonne of carbon saved). [34] With MRTS in Delhi, the incremental cost per tonne of CO_2 saved in carbon

equivalent is estimated to be US $14 (approximately). This provides a strong case for the MRTS in Delhi. The other related benefits as a result of its introduction would be the cost and time savings due to the decongestion effect.

Increasing the capacity of rail track

The rail freight transport service is expected to increase to 370 BTKM by the year 2000, while the road transport service to 570 BTKM. With specific energy consumption of 8 and 21 tonnes of oil equivalent per million tonne kilometre for the rail and road sectors respectively, the annual total energy demand for freight movement in 2000 would be about 15 mtoe, and CO_2 emission would be approximately 12.7 tc. In order to reduce the energy consumption and CO_2 emissions by one-third, an additional 380 BTKM of rail capacity will have to be provided. Assuming that completely new track and rolling stock are required to meet the demand of 380 BTKM, the total investment needed between now and 2001 is approximately Rs 540 billion (US $32.43 billion) based on estimates extrapolated from the Corporate Plan of the Railways. This will result in a CO_2 emission reduction of 4.2 tc per year.

With an assumed life of the entire system of 35 years, an investment of Rs 540 billion will result in saving 147 tc over 35 years giving a specific abatement cost of Rs 3673.5 (US $220.63)/tc. This cost does not include social benefits that may arise from increased rail traffic (such as reduced road congestion).

The above plan can be implemented as infrastructure to develop this additional capacity can be made available indigenously. The main constraint towards the enhancement of track capacity has been, and continues to be the lack of financial resources.

Technological change

Supply-side technological options for reducing carbon emissions in the transportation sector include both incremental and radical changes. Incremental changes involve fuel switching in private cars as well as in the public transportation system such as the replacement of coal-fired steam locomotives by higher-efficiency diesel and/or electric powered locomotives, or the replacement of diesel locomotives by electric ones.

More radical technological changes involve the introduction of new vehicle propulsion systems such as the replacement of internal combustion engines by electric motors or fuel cells and accompanying changes in vehicle design. Furthermore, entirely new infrastructure systems such as magnetic levitation trains (Maglevs) are being built in a number of developed countries. These technological options offer the possibility of drastically reducing carbon emissions or even achieving zero-carbon emissions.

More revolutionary technological change would be represented by massive introduction of a new generation of electric vehicles which, due to the high end-use efficiency of electric cars, would yield lower overall carbon emissions even if electricity were to be produced in oil-fired power plants.

In the case of reducing carbon emissions from private car usage, CNG (Compressed Natural Gas) vehicles appear to be the cheapest option, with carbon reduction potential of 30%. This is due to fuel efficiency improvements and generally lower fuel costs. Overall vehicle operating costs are lower, hence imply savings (negative carbon reduction costs). Similarly, the use of diesel and methanol fuels could reduce carbon emissions by about 20%. Thus, the attractiveness of CNG, diesel and methanol based options will vary according to specific national/regional contexts, which require detailed analysis.

Notes and References

[1] The level of motorization is measured as the growth in ownership and use of motorized vehicles.

[2] OECD—Organization for Economic Cooperation and Development—countries include the United States, Canada, most European countries, and Japan.

[3] Automotive Component Manufacturers Association of India, 1995. *Automotive Industry of India: Facts and Figures 1995*, Bombay.

[4] Faiz A, Sinha K, Walsh M, and Valma A. 1990. *Automotive Air Pollution: Issues and Options for Developing Countries*, WPS 492, World Bank, Washington, DC.

[5] International Energy Agency. 1993. *Energy Statistics and Balances for OECD Countries 1960–1991 & Energy Statistics and Balances for non-OECD countries 1971–91*, OECD, Paris.

[6] Grubler A. 1993. *The Transport Sector: Growing Demand and Emissions*. Presented at the Seminar on Population and Natural Resources, organized by the Tata Energy Research Institute, New Delhi, 30 September–1 October 1993.

[7] National Personal Transportation Survey. 1990. *Summary of Travel Trends and Public Use Data Tapes*, Federal Highway Administration, Washington, DC.

[8] Planning Commission. 1992. *Eighth Five Year Plan 1992–97*, Volume II, Government of India, New Delhi.

[9] Newman P and Kenworthy J. 1989. *Cities and Automobile Dependence: A Sourcebook*. Gower technical Publishers.

[10] World Bank. 1992. *World Development Report 1992–Development and the Environment*. Washington, DC.

[11] The *Montreal Protocol* (1987) and its strengthening revisions in the Second World Climate Conference in Geneva (1990) involved a public agreement among 55 countries for each to eliminate the use of CFCs within their boundaries. Fully halogenated CFCs are to be completely phased out of new vehicles by the year 2000 in developed countries, whilst developing countries have been provided an additional 10-year grace period.

[12] Faiz A, et al. 1994. *Air Pollution from Motor Vehicles—Draft*. Washington, DC: World Bank.

[13] Grubler A, et al. 1993. Emission Reduction at the Global Level. *Energy*, 18(5): 539–581.

[14] Central Statistical Organization. 1995. *National Accounts Statistics*. Government of India.

[15] Planning Commission. 1992. *Eight Five Year Plan: 1992–97*. New Delhi: Government of India.

[16] Automotive Component Manufacturers Association of India, *Automotive Industry of India: Facts & Figures 1992–93*. New Delhi.

[17] Tata Energy Research Institute. 1995. *TERI Energy Data Directory Yearbook 1995/96*. New Delhi.

[18] Government of India. *Census of India 1991: Final Population Totals: Rural-Urban Distribution*, Series 1, Paper 2 of 1991. New Delhi: Registrar General and Census Commissioner.

[19] *TRENDS '93: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Tennessee, USA, September 1994.

[20] Council of Scientific and Industrial Research and Ministry of Environment and Forests. 1992. *Global Change: Scientific Report Number 4*, *In* A P Mitra (ed).

[21] Tata Energy Research Institute. 1996. *Pre-Feasibility Study on the Prospects of High Speed Diesel Oil in India*, New Delhi.

[22] Mitra A P. 1993. *India and Global Change: Facilities, Inventories, Scenarios and Some New Angles*. Submitted to the Ministry of Environment and Forests, Government of India.

[23] Bose R K. 1994. Road Transport in Indian Metropolises: Energy Conservation and Emission Control Strategies. Paper presented at a workshop on *The Energy Environment Nexus—Indian Issues and Global Impacts*, 22–23 April, 1994. Philadelphia: University of Pennsylvania.

[24] Asian Energy Institute. 1991. *Collaborative Study on Strategies to Limit CO_2 Emissions in Asia and Brazil*, New Delhi: AEI.

[25] Springmann F. 1991. *Analysis of the Ecological Impact of Demonstration Projects in the Field of Rational Use of Energy: Development of Evaluation Criteria*. Study on behalf of the European Communities, Directorate General for Energy (DG XVII), Regio-Tec GmbH, Starnberg, Germany.

[26] Grubler A, et al. 1993. *Emission Reduction at the Global Level*, *Energy*, 18(5): 539–581.

[27] Committee on Science, Engineering and Public Policy. 1991. *Policy Implications of Greenhouse Warming*. Report of the Mitigation Panel, US National Academy of Sciences, US National Academy of Engineering and Institute of Medicine, US National Academy Press, Washington, DC, USA.

[28] Government of India. 1987. *Report of the Study Group on Alternative Systems of Urban Transport*. New Delhi: Ministry of Urban Development.

[29] BAU scenario assumes that the present trends of vehicular growth will continue, and fuel efficiency norms, modal split pattern, and occupancy levels will remain unchanged till 2001.

[30] Carvalho B and Halarnkar S. 1996. The Auto Industry Hits a Roadblock, *Business World*, 17–30 April 1996, pp. 114–117.

[31] *ibid.*

[32] Bose R K. 1994. *Delhi MRTS—Global Environmental Benefits.* Prepared for the Ministry of Urban Development, Government of India.

[33] Rail India Technical and Economic Service Ltd, 1989. *Mass Rapid Transport System for Delhi–Report on Phase 1A*, New Delhi.

[34] Global Environmental Facility. 1995. *GEF Operational Strategy*, February.